THIS PAGE BLANK (USPTO)

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : B29C 47/14, D02G 3/00

A1

(11) International Publication Number: WO 99/19131

(43) International Publication Date: 22 April 1999 (22.04.99)

(21) International Application Number: PCT/US98/21378

(22) International Filing Date: 9 October 1998 (09.10.98)

(30) Priority Data:
60/061,460 9 October 1997 (09.10.97) US

(71) Applicant (*for all designated States except US*): HILLS, INC. [US/US]; 7785 Ellis Road, W. Melbourne, FL 32904 (US).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): HAGGARD, Jeffrey, S. [US/US]; 560 Amber Lane, Cocoa, FL 32926 (US). WILKIE, Arnold, E. [US/US]; 7850 S. Tropical Trial, Merritt Island, FL 32952 (US). HARRIS, Frank, O. [US/US]; Route 1, Box 970, Rogersville, TX 37857 (US). DUGAN, Jeffrey, Scott [US/US]; 109 Fishery Loop Road, Erwin, TN 37650 (US).

(74) Agents: FINNAN, Patrick, J. et al.; Epstein, Edell & Retzer, Suite 400, 1901 Research Boulevard, Rockville, MD 20850 (US).

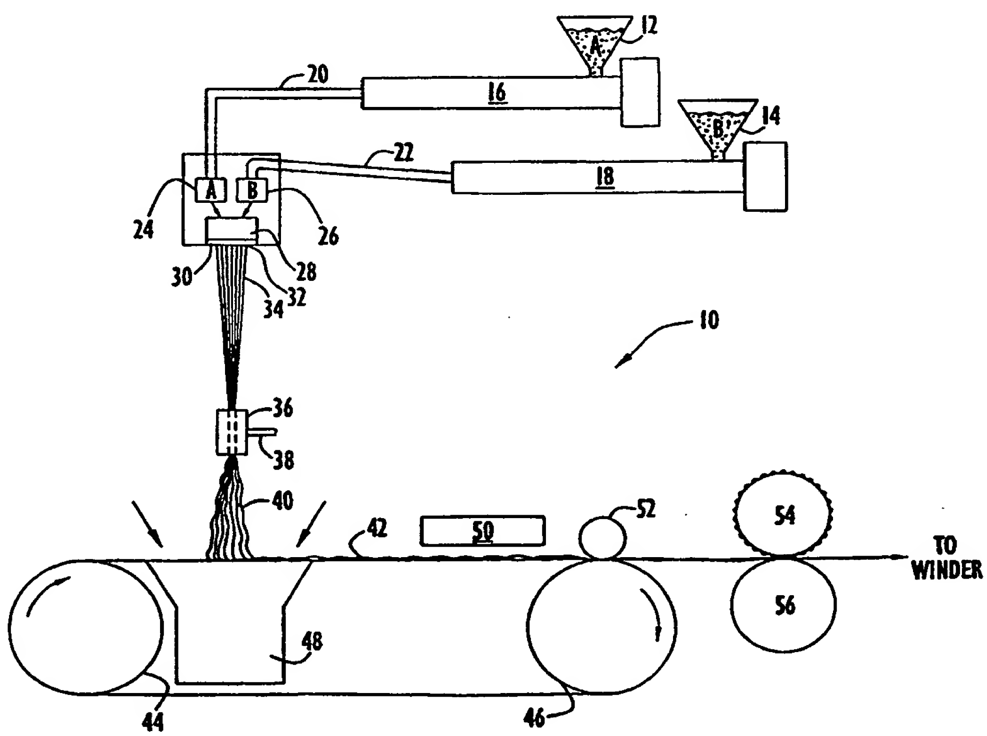
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: METHOD AND APPARATUS FOR IN-LINE SPLITTING OF PLURAL-COMPONENT FIBERS AND FORMATION OF NONWOVEN FABRICS

(57) Abstract

In-line fiber splitting in a spunbond process is achieved by differential heat shrinkage of two or more components of a plural-component fiber, such as a ribbon-shaped bicomponent fiber to produce a nonwoven fabric having superior properties. Two polymers that shrink to substantially different degrees upon application of heat are extruded from an array of orifices (32) of a spinneret (30) as components of plural-component fibers. Ribbon-shaped fibers having alternating first and second components having a difference in heat shrinkage of at least approximately ten percent result in a high degree of rapid separation of the fiber components. The array of plural-components fibers is drawn through an aspirator (36) and attenuated prior to being deposited on a web-forming belt (42) and conveyed to a heater (50) which heats the web to a temperature sufficient to cause differential heat shrinkage of the polymer components, thereby causing the fiber segments formed of the components to separate in less than approximately a second. After fiber separation, the web is bonded to form the nonwoven fabric.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania
AM	Armenia
AT	Austria
AU	Australia
AZ	Azerbaijan
BA	Bosnia and Herzegovina
BB	Barbados
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BJ	Benin
BR	Brazil
BY	Belarus
CA	Canada
CF	Central African Republic
CG	Congo
CH	Switzerland
CI	Côte d'Ivoire
CM	Cameroon
CN	China
CU	Cuba
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
GE	Georgia
GH	Ghana
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IL	Israel
IS	Iceland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgyzstan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakstan
LC	Saint Lucia
LI	Liechtenstein
LK	Sri Lanka
LR	Liberia
LS	Lesotho
LT	Lithuania
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
MK	The former Yugoslav Republic of Macedonia
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
MX	Mexico
NE	Niger
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SN	Senegal
SZ	Swaziland
TD	Chad
TG	Togo
TJ	Tajikistan
TM	Turkmenistan
TR	Turkey
TT	Trinidad and Tobago
UA	Ukraine
UG	Uganda
US	United States of America
UZ	Uzbekistan
VN	Viet Nam
YU	Yugoslavia
ZW	Zimbabwe

METHOD AND APPARATUS FOR IN-LINE SPLITTING OF PLURAL-COMPONENT FIBERS AND FORMATION OF NONWOVEN FABRICS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority from U.S. Provisional Patent Application Serial No. 60/061,460, entitled "In Line Splitting of Bicomponent Fibers in Nonwovens Processes and Fabrics", filed October 9, 1997. The disclosure of that provisional patent application is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

Field of the Invention:

The present invention relates to a method and apparatus for producing nonwoven fabrics and, in particular, to a spunbond process for manufacturing fabrics wherein individual constituent fiber components of extruded plural-component synthetic fibers are separated by differential heat shrinkage into microfibers in line with the extrusion of the plural-component fibers.

Description of the Related Art

Various attempts have been made to produce nonwoven fabrics having improved characteristics, such as greater bulkiness and softness, superior flexibility and drape, and better barrier and filtration properties for use in products such as disposable absorbent articles, medical garments and filtration materials. It has been found that nonwoven fabrics having desirable qualities can be manufactured from splittable plural-component fibers. Such plural-component fibers typically include at least two different polymers arranged as microfilaments or segments across the cross section of the fiber, which segments extend continuously along the length of the fiber. By separating these plural-component fibers into their constituent segments after extrusion, a fine denier fabric with desirable characteristics can be produced.

A number of known techniques have been used to separate the individual segments of plural-component fibers. Specifically, fiber segments can be separated by applying mechanical force to the fibers, such as high pressure water jets, beating, carding, calendering, or other mechanical working of the fibers. Alternatively, one of the components of the plural-component fibers can be dissolved by a solvent applied to the fiber, such that segments formed of the undissolved component remain.

U.S. Patent No. 5,783,503 to Gillespie et al., incorporated herein by reference in its entirety, discloses splitting plural-component fibers during free fall from a spinneret from which the fibers are extruded, and prior to deposition of the fibers onto a collection surface such as a forming table or belt. U.S. Patent No. 5,783,503 discloses a number of possible techniques for splitting the fibers, including: drawing and stretching or attenuating the fibers in a pressurized gaseous stream of air or steam; developing a triboelectric charge in at least one of the components; applying an external field to the fibers; and subjecting the falling fibers to air turbulence. These techniques rely on a number of properties of the different polymer components, including: miscibility, differences in melting points, crystallinity, viscosity, conductivity, and the ability to develop a triboelectric charge.

Since the system disclosed in U.S. Patent No. 5,783,503 requires the separation process to be essentially completed during free fall of the fibers and prior to deposition of the fibers onto the forming surface, it is necessary to position additional equipment or equipment having specific features along the vertical path of the fibers to effect separation. For example, means for producing attenuation at a specific low pressure, means for applying steam, means for providing increased air turbulence, and/or means for applying an external electric field may be necessary to achieve adequate fiber splitting. The equipment required to produce these effects may significantly increase the complexity or expense of the system and may constrain the process to certain operational parameters. Further, it may be necessary to mix additives into the polymers in order to modify properties of the polymers to achieve adequate separation.

U.S. Patent No. 5,759,926, incorporated herein by reference in its entirety, discloses another technique for separating segments of plural-component fibers, wherein a hot aqueous solution is applied to the web to induce splitting. Specifically,

the fiber web is transported through a hot water bath or sprayed with steam or a mixture of steam and air. At least one of the polymer components of the plural-component fibers must be naturally hydrophilic or hydrophilically modified, and the polymers must have a difference in solubility parameter of at least 0.5 $(cal/cm^3)^{1/2}$. When the water or steam is applied to the web, the segments formed of the hydrophilic polymer adsorb the moisture and separate from the less or non-hydrophilic polymer segments. That is, the mechanism used to achieve fiber separation is the adsorption of water by the hydrophilic polymer.

The system disclosed in U.S. Patent No. 5,759,926 has a number of significant limitations. Because separation of the fiber segments is caused by adsorption of water, it may be necessary to expose the fibers to the hot aqueous solution for a substantial period of time. Specifically, the separation process can take up to thirty seconds to complete, thereby significantly limiting the rate at which the web can be transported and formed. Moreover, because the process requires application of a hot aqueous solution to the web, a drum drier is required to dry the web prior to bonding, which adds a time consuming step and substantially increases the cost and complexity of the system.

Accordingly, there remains a need for a system capable of achieving in-line fiber splitting in a simple, inexpensive and rapid spunbond process to form nonwoven fabrics having a fine denier and good fabric characteristics.

SUMMARY OF THE INVENTION

It is an object of the present invention to produce a nonwoven fabric having superior properties, such as good coverage (i.e., no openings or gaps), bulkiness, softness, flexibility and drape, and good barrier properties.

It is a further object of the present invention to achieve a high degree of separation between segments of plural-component fibers in an in-line spunbond process to produce a nonwoven fabric having a fine denier.

It is another object of the present invention to rapidly separate constituent fiber segments of plural-component fibers in an in-line spunbond process using a relatively simple, reliable and inexpensive mechanism.

It is yet another object of the present invention to employ differential heat shrinkage of polymer components to cause separation of fiber segments of plural-component fibers.

The aforesaid objects are achieved individually and in combination, and it is not intended that the present invention be construed as requiring two or more of the objects to be combined unless expressly required by the claims attached hereto.

According to the present invention, in-line fiber splitting in a spunbond process is achieved by differential heat shrinkage of two or more components of a plural-component fiber, such as a ribbon-shaped bicomponent fiber. Two or more polymers that shrink to substantially different degrees upon application of heat are extruded from an array of orifices of a spinneret as interleaved or alternating components of plural-component fibers. The array of plural-component fibers is drawn through an aspirator and attenuated prior to being deposited on a web-forming belt. Once on the belt, the fiber web is conveyed to a heater which heats the web to a temperature sufficient to cause differential heat shrinkage of the polymer components, thereby causing the fiber segments formed of the components to separate. After fiber separation, the web is bonded to form the nonwoven fabric.

To achieve a high degree of rapid separation, the polymer components of the plural-component fibers of the present invention preferably have a difference in heat shrinkage of at least approximately ten percent. It has been found by the present inventors that a bicomponent ribbon-shaped fiber having alternating first and second fiber segments respectively formed of two different polymer components results in superior component separation and produces a nonwoven fabric with exceptional qualities.

Heating of the web to cause differential shrinkage is accomplished using blown hot air, blown steam, radiant heat, or other methods of applying heat and combinations thereof. The heating unit, disposed along the web transport path, heats the fibers to a temperature sufficient to effect differential shrinkage and fiber splitting, preferably in less that one second.

The quick separation obtained using differential heat shrinkage of the fiber components makes it possible to produce a spunbonded fabric, wherein component

separation takes place in-line with fiber extrusion in a spunbond process. Specifically, when fiber component separation is achieved in seconds or less than a second, the web bonding can be done in an in-line operation immediately following fiber extrusion, web formation and fiber component separation. The in-line spunbond process of the present invention produces a fine denier nonwoven fabric having desirable properties such as improved bulkiness, softness, flexibility, drape, and barrier and filtration properties.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of a specific embodiment thereof, particularly when taken in conjunction with the accompanying drawings wherein like reference numerals in the various figures are utilized to designate like components.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagrammatic view of an apparatus for performing a spunbond process employing fiber splitting in line with fiber extrusion to form a nonwoven fabric.

Fig. 2 is a cross-sectional view of a bicomponent fiber having a circular cross section and wedge-shaped segments.

Fig. 3 is a cross-sectional view of a hollow bicomponent fiber having a circular cross section.

Fig. 4 is a cross-sectional view of a five-segment bicomponent fiber having a cross-shaped cross section.

Fig. 5 is a cross-sectional view of a nine-segment bicomponent fiber having a cross-shaped cross section.

Fig. 6 is a cross-sectional view of a ten-segment ribbon-shaped bicomponent fiber.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In accordance with an exemplary embodiment of the present invention, in-line fiber splitting in a spunbond process is achieved by differential heat shrinkage of two or more components of a plural-component fiber, such as a ribbon-shaped fiber or a

fiber with another suitable cross-sectional shape. The term "spunbond" refers to a process of forming a nonwoven fabric or web from small diameter fibers or filaments produced by extruding molten polymers from orifices of a spinneret. The filaments are drawn as they cool and are randomly laid on a forming surface, such that the filaments form a nonwoven web. The web is subsequently bonded using one of several known techniques to form the nonwoven fabric. The term "in-line", as used herein refers to a process wherein fiber extrusion, splitting and web formation are performed in a single, continuous process (i.e., not in-line would be if the extruded fibers are made into a roll and then split or formed into a web separately).

Fig. 1 diagrammatically illustrates an apparatus 10 for producing a nonwoven fabric according to the spunbond process of the present invention. Apparatus 10 includes hoppers 12 and 14 into which pellets of two different polymers, polymers A and B described hereinbelow, are respectively placed. Polymers A and B are respectively fed from hoppers 12 and 14 to screw extruders 16 and 18 which melt the polymers. The molten polymers respectively flow through heated pipes 20 and 22 to metering pumps 24 and 26, which in turn feed the two polymer streams to a suitable spin pack 28 with internal parts for forming bicomponent fibers of a chosen cross-section and number of segments. As used herein, the terms "segment" and "microfiber" refer to a portion of a fiber having a composition that is distinct from the composition of another portion of the fiber, and the term "bicomponent" refers to a fiber having two or more segments, wherein at least one of the segments comprises one material or component (e.g., a polymer), and the remaining segments comprise another, different material or component. The term "plural-component", as used herein, refers to a fiber having two or more segments, wherein each segment comprises one of at least two different materials or components which make up the fiber (thus, a bicomponent fiber is a type of plural-component fiber).

Spin pack 28 includes a spinneret 30 with orifices 32 which shape the bicomponent fibers extruded therethrough. For example, orifices 32 may be arranged in a substantially horizontal, rectangular array, with each orifice extruding an individual plural-component fiber.

Various bicomponent fiber cross-sections that are suitable for use with the present invention are shown in Figs. 2-6. A fiber having a substantially round cross-section with eight wedge-shaped segments or "pieces of pie" is shown in Fig. 2. The wedge-shaped segments are alternately formed of two different polymers A and B, such that adjacent segments are formed of different polymers. Fibers having the cross-section shown in Fig. 2 and methods of making them are disclosed in U.S. Patent No. 3,117,362, the disclosure of which is incorporated herein by reference in its entirety.

While the plural-component fiber arrangement shown in Fig. 2 is generally suitable for the present invention, difficulty in separating the fiber segments can be encountered, particularly where the segments do not meet at a sharp point at the fiber center. Fig. 3 illustrates a plural-component fiber having a cross-section similar to that shown in Fig. 2, except that the fiber is hollow, such that the wedge-shaped segments do not extend completely to the center. Because the segments made of like polymers cannot be connected to each other near the fiber center, the segments of the hollow fiber shown in Fig. 3 more readily and consistently separate than those of the solid plural-component fiber shown in Fig. 2. The fiber shown in Fig. 3 can be made using the same extrusion technique as the fiber shown in Fig. 2 but with a spinneret that produces a hollow fiber. Fibers of this type are disclosed in U.S. Patent Nos. 4,051,287 and 4,109,038, the disclosures of which are incorporated herein by reference in their entirety.

Fig. 4 illustrates a five-segment plural-component fiber having a cross section in the shape of a cross, wherein four polymer A segments extend radially outward at four, 90°-spaced points from a central, polymer B segment. Fig. 5 illustrates another cross-shaped plural-component fiber cross section, having a central, polymer B segment, four, 90°-spaced polymer A segments extending radially from the central segment, and four additional polymer B segments extending radially further outward from the ends of the four polymer A segments, respectively, for a total of nine separable segments.

A ten-segment bicomponent fiber having a ribbon-shaped cross-section with alternating polymer A and polymer B segments disposed side-by-side is shown in Fig. 6. Each segment adjoins adjacent segments along lines extending substantially

perpendicular to the longer edge of the ribbon, such that the segments have a generally rectangular cross section. It has been experimentally found by the present inventors that, where splitting of the fiber segments is achieved using differential heat shrinkage of two different polymer components, the plural-component fiber having a ribbon-shaped cross-section provides faster and more complete segment separation relative to plural-component fibers having other cross sections. Moreover, when incomplete splitting of the fibers occurs, the ribbon-shaped fiber still results in a very soft fabric relative to other fiber cross-sections, because of the shape of the ribbon produces a very low bending modulus (i.e., the unseparated portions of the ribbon fibers can still twist and bend in three dimensions, and the adjoining separated portion of the fibers have a high degree of freedom to bend in different directions relative to each other). Thus, in accordance with the present invention, use of plural-component fibers having a ribbon-shaped cross section with segments of alternating components is preferable to use of plural-component fibers having the other cross sections described hereinabove, because: 1) they split easily and almost totally; and 2) to the extend that the fiber segments do not separate, the unsplit ribbon-shaped fiber is by far softer than unsplit fibers of other cross sections.

Referring again to Fig. 1, an array of bicomponent or plural-component fibers 34 exit the spinneret 30 of spin pack 28 and are pulled downward and attenuated by an aspirator 36 which is fed by compressed air or steam from pipe 38. Aspirator 36 can be, for example, of the gun type or of the slot type, extending across the full width of the fiber array, i.e., in the direction corresponding to the width of the web to be formed by the fibers. A typical spinneret and aspirator arrangement useful for this process is illustrated in U.S. Patent No. 3,802,817, the disclosure of which is incorporated herein by reference in its entirety.

Aspirator 36 delivers attenuated fibers 40 onto a web-forming screen belt 42 which is supported and driven by rolls 44 and 46. A suction box 48 is connected to a fan (not shown) to pull room air (at the ambient temperature) through screen belt 42 and cause fibers 40 to form a nonwoven web on screen 42.

Once the web is formed on screen 42, the web is heated to cause differential heat shrinkage of the two component materials of the fibers. Specifically, when heated

to a temperature below their melting points, one of polymers (e.g., polymer B) shrinks, relative to its unheated size, more than the other polymer (e.g., polymer A) shrinks relative to its unheated size. A difference in heat shrinkage between the two polymers can be measured as the percent shrinkage of polymer B minus the percent shrinkage of polymer A. When the difference in heat shrinkage is significant, crimping and separation of the fiber segments occurs. A high degree of crimping and splitting (separation) of the plural-component fibers is desirable, since a lofty or bulky nonwoven fabric having good softness, flexibility and drape characteristics and barrier properties results.

It has been experimentally found by the present inventors that two components of a plural-component fiber having a difference in heat shrinkage of at least approximately ten percent provide a high degree of rapid separation of the components of the fiber into individual segments under the heating conditions of the present invention, and higher heat shrinkage differences result in even more complete and rapid separation. Conversely, it has been experimentally found by the present inventors that, in the absence of other split-inducing measures, with polymers having a difference in heat shrinkage of less than approximately ten percent, reduced or insufficient separation of the segments results, and additional measures may be required to sufficiently separate the segments of the plural-component fibers. Consequently, in accordance with the present invention, the polymers of the extruded plural-component fibers preferably have a difference in heat shrinkage of at least approximately ten percent under the heating conditions applied in the system of the present invention (e.g., taking into account the velocity of the fibers exiting the aspirator, the fiber and microfiber deniers and the weight of the web per unit area, the speed of the belt, the temperature and duration of the heat applied and the type of heat). More preferably, the polymers of the extruded plural-component fibers have a difference in heat shrinkage of at least approximately twenty percent, and still more preferably greater than twenty-five percent.

A particularly advantageous combination of polymers has been found by the present inventors to be the combination of polypropylene (polymer A) and polyethylene terepthalate (PET) modified with 20 mole percent purified isopthalic acid and a

powdered transesterification inhibitor (GE Ultranox 626) (polymer B), which have a difference in heat shrinkage of approximately thirty percent under the heating conditions of the present invention.

Referring once again to Fig. 1, to differentially heat shrink the plural-component fibers, the web formed on web-forming belt 42 passes in close proximity to (e.g., directly under or over) a heating unit 50 which causes the temperature of the fibers of the web to increase to a temperature at which differential heat shrinkage of polymers A and B occurs, thereby causing the plural-component fibers to separate into their constituent segments. That is, the temperature of the web is raised to a temperature below the melting points of polymer A and polymer B but high enough to sufficiently shrink at least one of the two polymers to cause separation between adjacent segments of the fibers. As used herein, the terms "separation" and "separate" connote substantial detachment of segments from adjacent segments along at least a substantial portion of the longitudinal extent of the segments, but do not require total separation (although total separation or nearly total separation is desirable and can be achieved with certain polymer and process combinations).

Although substantial crimping of the fibers is not required by the present invention, some crimping of the fibers may occur in addition to fiber splitting to further increase the softness and bulkiness of the fabric. For example, some degree of crimping of the fiber segments typically occurs at the time of initial shrinkage, the segments of the unseparated portions of the fibers experience significant crimping due to the shrinkage difference between the unseparated segments, and the segments of the separated portions of the fibers may also experience some degree of crimping, depending on the particular polymer components and the process conditions.

Heating unit 50 can supply any type of heat suitable for causing differential heat shrinkage and separation of the fiber components, including, but not limited to: hot air blown through the web (convection heating); steam blown through the web; radiant heat; and combinations thereof. As used herein, the terms "heater" and "heating unit" may include a single heater element or device or multiple heaters arranged serially along the web-conveying belt. It should be understood that, while the heat applied may be in the form of steam, separation of the components is caused by the heating of the

fiber and not as a result of adsorption of moisture or because the heat is conveyed in the form of moisture. That is, the polymer components of the plural-component fibers of the present invention need not be hydrophilic; in fact, the polymer components of the fibers of the present invention preferably are not hydrophilic.

The use of heat to separate fiber segments by differential heat shrinkage in accordance with the present invention results in much faster separation than prior art systems relying on adsorption of water by a hydrophilic polymer to separate plural-component fibers. For example, use of heat to separate the above-described polypropylene and modified PET polymers results in rapid and nearly total separation of the segments formed of these polymers when heat is applied to a portion of a moving web for less than approximately one second. Specifically, the modified PET begins to experience significant heat shrinkage when the fibers are heated to temperatures above approximately 200 °F, which can be reached very quickly with blown hot air or steam or even radiant heat. In the experimental examples, the temperature of the web was rapidly raised to 250 °F ± 15 °F, immediately causing a high degree shrinkage of the modified PET and, consequently, fiber segment separation (under these conditions, polypropylene does not experience significant shrinkage).

It has been found by the present inventors that the time required to heat a portion of the web in order to substantially complete the shrinkage process and cause separation of the fibers is a function of the fabric thickness or weight per unit area, with heating time increasing generally linearly with unit thickness or weight. Further, within the range of temperatures which cause differential heat shrinkage, higher temperatures reduce the time required to substantially complete the shrinkage process. The heating time can be controlled by the speed of the belt conveying the web and/or the length of the portion of the web directly receiving heat from the heater (i.e., the length of the heater in the belt moving direction). Preferably, the heating parameters are such that differential shrinkage can be completed in less than approximately one second so that the heating unit is of a reasonable length at the belt speeds typically used in to manufacture nonwoven fabrics in an in-line spunbond process (e.g., hundreds of meters/minute).

Referring yet again to Fig. 1, after heat is applied to cause differential heat shrinkage and separation of the plural-component fibers, the web passes through an optional compaction roll 52 and then leaves the screen and passes through a nip formed by heated calender rolls 54 and 56. One of the calender rolls is embossed to have raised nodules which fuse the fibers together only at the points where the nodules contact the web, leaving the fibers between the bond points still bulky and giving the resultant bonded nonwoven fabric good flexibility and drape.

The present invention is not limited to above-described bonding process, and other conventional bonding techniques can be employed, including, but not limited to: through-air bonding (particularly useful with the low melt temperature normally seen with high shrinkage components); needle punching; and hydroentangling (i.e., use of high-pressure water jets). In particular, in accordance with the through-air bonding technique, as heat is applied to the web, the temperature of the web rises to a point at which differential shrinkage of the high-shrinkage polymer component occurs. As heat continues to be applied, the temperature of the web rises to a temperature to a point at which the high-shrinkage polymer becomes tacky and begins to melt, allowing the segments formed of high-shrinkage polymer to bond to adjacent polymers.

While described in the context of a spunbond process, the differential heat shrinkage technique of the present invention can be applied to web or fabric forming processes that do not require bonding of the fibers. For example, the differential heat shrinkage technique can be applied in spunlaid processes.

The present invention is not limited to the particular apparatus and processes described in connection with Fig. 1, and additional or modified processing techniques are considered to be within the scope of the invention. For example, one or more godets may be used prior to the aspirator for drawing and/or relaxing the fibers. A downstream godet may be operated at higher speed than an upstream godet to stretch the fibers, or a downstream godet may be operated at a lower speed than an upstream godet to relax the fibers.

While the above-described -mbodiment of the present invention relies principally on differential heat shrinkage of the web after deposition of the plural-component fibers on the web-forming surface, in accordance with the present invention, measures may

be taken to effect differential heat shrinkage and fiber splitting prior to deposition of the fibers onto the web-forming surface. Techniques which result in splitting or partial splitting of the fibers before laydown on the web-forming belt may result in a fabric with better coverage (free of open areas in the web) as well as the other advantageous fabric qualities described herein, as the fiber segments are able to lay down on the belt independently of each other, in a manner as if the segments had been actually spun with low deniers on the order of 0.1 denier/filament. Specifically, the aforementioned godet(s) may be heated to assist the differential heat shrinkage of the fibers to facilitate splitting, and/or another conductive heating device, such as a hot plate, can be employed for this purpose.

Hot air and/or steam (saturated or superheated) can be applied to the fibers in the aspirator to cause the differential heat shrinkage fiber components to split before reaching the belt. A similar result can be achieved by direct heating of the aspirator to a temperature warm enough to induce differential shrinkage (but not warm enough to melt either component).

Various splitting aids can also be employed, including, but not limited to: fluoropolymer or silicone compounds in one or more of the polymer components to make the components slippery and more prone to split; foaming agents in one or more of the components which induce swelling of one component relative to the other component; and use of ultrasonics in addition to heat to excite the two polymer components to enhance relative movement and splitting.

The fine fiber segments separated by the system of the present invention produce a desirably softer fabric with greater loftiness and bulkiness than nonwoven fabrics made from known spunbond processes. Various additional improved fabric properties, such as good fabric drape, high filtration, barrier properties, and coverage at low weight are also achieved with the ultra-low denier per filament resulting from the split fibers of the present invention. The nonwoven fabric formed by the process of the present invention is useful in any product where a fluffy nonwoven fabric is useful, such a thin sheets of padding. The nonwoven fabric of the present invention can be used in a variety of other commercial products including, but not limited to: softer diaper liners

or other disposable absorbent articles; medical fabrics having barrier properties; and filtration media.

The following examples, carried out using the apparatus shown in Fig. 1, are provided for illustration purposes, and the invention is not limited thereto.

EXAMPLES

Example 1

A spinpack was utilized which produced 198 self-crimping fibers in a rectangular array, each fiber having a ten-segment, ribbon cross-section, with alternating polymer A and polymer B segments, as shown in Fig. 6. Polymers A and B were pumped at equal rates of 0.20 grams/minute/spinneret orifice, totaling 0.41 grams/minute/spinneret orifice. Each spinneret orifice was 0.8 mm long and had a 0.2 mm x 2.0 mm cross-section to produce the ribbon-shaped fibers.

Polymer A was 12 MFR polypropylene. Polymer B was a high shrinkage type of co-polyester obtained from Amoco Chemical Company, specifically, polyethylene terepthalate modified with 20 mole percent purified isopthalic acid and a powdered transesterification inhibitor (GE Ultranox 626). The extruded ribbon fibers were drawn through an aspirator having a six inch wide slot with a 0.015 inch gap. Room temperature compressed air at 20 psig was used to feed the aspirator, producing a fiber velocity through the six inch wide slot aspirator of approximately 3000 meters/minute. No appreciable splitting of the ribbon fibers exiting the aspirator was observed.

The attenuated fibers exiting the aspirator were delivered onto a screen belt, forming a web four inches wide. The belt speed was set to 30 meters/minute to yield a fabric weight of 1.6 ounces/square yard. The fiber denier was 1.6, giving 0.16 denier for each of the 10 segments in each ribbon fiber. A radiant heater was positioned one inch above the web lying on the belt. The heating area was approximately 20 inches in the belt running direction and six inches in the width direction. Twelve hundred (1200) watts of radiant heat (approximately 10 watts/sq. inch, heating the web to 250°F ±15°F for approximately 1 second) from the heater was used to differentially shrink the fibers, thereby crimping and separating the individual fiber segments to yield a very soft, bulky web.

The web was passed through a compaction roll having a compaction roll pressure of 40 pounds per inch of width. The web was hot pattern calendered, with a calender roll temperature of 220°F, yielding a fabric with good softness and drape as well as exceptional coverage, filtration and barrier properties.

Example 2

Example 1 was repeated with the same setup, except that the pump speeds were reduced equally so that each spinning orifice delivered 0.18 grams/minute (0.09 grams/minute for each polymer), and the aspirator air pressure was reduced to 15 psig, resulting in a fiber exit velocity from the aspirator of 1900 meters/minute. The fiber denier was 1.1 (0.11 denier per segment). The belt speed of 30 meters/minute yielded a fabric weight of 0.5 ounce/square yard of fabric. Again, a desirable fabric with exceptional softness and other properties was produced.

Example 3

Example 1 was repeated with the same setup, except that the pump speeds were increased equally so that each spinning orifice delivered 0.7 grams/minute (0.35 grams/minute for each polymer), and the aspirator air pressure was increased to 25 psig, resulting in a fiber exit velocity from the aspirator of 5000 meters/minute, and the fiber denier was 2.5 (0.25 denier per segment). The belt speed of 30 meters/minute yielded a fabric weight of 0.5 ounce/square yard of fabric. Again, a desirable fabric with exceptional softness and other properties was produced.

To produce a fabric with a finer denier, the above example can be repeated with ribbon fibers having 20 or 40 segments of alternating A and B polymers. Thus, for example, at a belt speed of 30 meters/minute, yielding a fabric weight of 0.5 ounce/square yard of fabric with a fiber denier of 2.4, a 20 segment fiber results in a 0.12 denier per segment fabric, and a 40 segment fiber results in a 0.06 denier per segment fabric.

In a manufacturing environment, to economically produce a nonwoven fabric in an in-line spunbond process, the belt speed is preferably an order of magnitude higher than the belt speed used in the above experiment (e.g., up to approximately 600 mpm).

The rapid (e.g., a fraction of a second) separation of the plural-component fibers achieved by the differential heat shrinkage technique of the present invention allows nonwoven fabrics formed from split, plural-component fibers to be manufactured in an in-line spunbond process at these high belt speeds with a heating unit and belt of a modest length, thereby making in-line spunbond processing of splittable plural-component fibers more economically attractive.

As can be seen from the above examples, a fine denier nonwoven fabric having desirable properties such improved bulkiness, softness, drape, and barrier properties can be produced from the in-line spunbond process of the present invention employing differential heat shrinkage of ribbon-shaped plural-component fibers to cause a high degree of fiber segment separation.

Having described preferred embodiments of a new and improved method and apparatus for in-line splitting of plural-component fibers and formation of nonwoven fabrics, it is believed that other modifications, variations and changes will be suggested to those skilled in the art in view of the teachings set forth herein. It is therefore to be understood that all such variations, modifications and changes are believed to fall within the scope of the present invention as defined by the appended claims.

What is Claimed is:

1. A method of forming a nonwoven fabric from a process employing fiber splitting in line with fiber extrusion, the method comprising the steps of:

extruding an array of plural-component fibers, each comprising first and second materials having a relative difference in heat shrinkage;

depositing the array of plural-component fibers onto a moving surface to form a web;

applying heat to the web to cause separation between segments of the plural-component fibers comprising the first material and segments of the plural-component fibers comprising the second material due to differential heat shrinkage of the first and second materials; and

processing the web to form the nonwoven fabric.

2. The method according to claim 1, wherein said processing step includes bonding of the web to form a spunbonded fabric.

3. The method according to claim 1, wherein the first and second materials have a difference in heat shrinkage of at least approximately ten percent.

4. The method according to claim 1, wherein said applying step includes blowing hot air, steam or a combination of hot air and steam through the web.

5. The method according to claim 1, wherein said applying step includes applying radiant heat to the web.

6. The method according to claim 1, wherein said first and second materials are non-hydrophilic.

7. The method according to claim 1, wherein said extruding step includes forming the plural-component fibers as ribbon-shaped fibers.

8. The method according to claim 7, wherein the ribbon-shaped fibers comprise segments of the first material interleaved with segments of the second material.

9. The method according to claim 8, wherein the ribbon-shaped fibers are bicomponent fibers comprising alternating segments of the first material and segments of the second material.

10. The method according to claim 1, wherein said extruding step includes forming plural-component fibers having a cross section in the shape of a cross, including a central segment comprising the first material and a plurality of radial segments comprising the second material and extending radially outward from the central segment.

11. The method according to claim 10, wherein the plural-component fibers formed in said extruding step further include a plurality of radial segments comprising the first material and extending radially outward from said plurality of radial segments comprising the second material.

12. The method according to claim 1, wherein said applying step includes moving the web past a heating unit at a rate that allows the segments of the plural-component fibers of a portion of the web to separate while the portion of the web is receiving heat from the heating unit.

13. The method according to claim 12, wherein the portion of the web receives heat from the heating unit for less than approximately one second.

14. The method according to claim 1, wherein differential heat shrinkage of the segments of a portion of the web and resultant fiber separation is substantially completed from application of less than approximately one second of heat.

15. The method according to claim 1, wherein said extruding step includes extruding plural-component fibers comprising: polypropylene; and polyethylene terepthalate modified with isopthalic acid and a powdered transesterification inhibitor.

16. The method according to claim 1, further comprising the step of attenuating the extruded array of plural-component fibers prior to depositing the array of plural-component fibers onto the moving surface.

17. The method according to claim 16, wherein said attenuating step includes drawing the array of plural-component fibers through an aspirator.

18. The method according to claim 16, wherein said attenuating step includes using at least one godet to draw or relax the array of plural-component fibers.

19. The method according to claim 1, wherein application of heat to the web causes the plural-component fibers to crimp.

20. The method according to claim 1, wherein no substantial separation of the segments of the plural-component fibers occurs prior to application of the heat to the web.

21. The method according to claim 1, wherein said processing step comprises through-air bonding of the web by heating the web to a temperature at which segments formed of one of said first and second materials begin to melt and adhere to adjacent segments.

22. A method of forming a nonwoven fabric from a process employing fiber splitting in line with fiber extrusion, the method comprising the steps of:

extruding an array of plural-component fibers, each comprising first and second materials having a relative difference in heat shrinkage;

applying heat to the array of plural-component fibers to cause separation between segments of the plural-component fibers comprising the first material and segments of the plural-component fibers comprising the second material due to differential heat shrinkage of the first and second materials;

depositing the separated plural-component fibers onto a moving surface to form a web; and

processing the web to form the nonwoven fabric.

23. The method according to claim 22, wherein said processing step includes bonding of the web to form a spunbonded fabric.

24. The method according to claim 22, wherein the first and second materials have a difference in heat shrinkage of at least approximately ten percent.

25. The method according to claim 22, wherein said applying step includes blowing hot air, steam or a combination of hot air and steam through the array of plural-component fibers.

26. The method according to claim 22, wherein said applying step includes applying radiant heat to the array of plural-component fibers.

27. The method according to claim 22, wherein said first and second materials are non-hydrophilic.

28. The method according to claim 22, wherein said extruding step includes forming the plural-component fibers as ribbon-shaped fibers.

29. The method according to claim 28, wherein the ribbon-shaped fibers comprise segments of the first material interleaved with segments of the second material.

30. The method according to claim 29, wherein the ribbon-shaped fibers are bicomponent fibers comprising alternating segments of the first material and segments of the second material.

31. The method according to claim 22, wherein said extruding step includes forming plural-component fibers having a cross section in the shape of a cross, including a central segment comprising the first material and a plurality of radial segments comprising the second material and extending radially outward from the central segment.

32. The method according to claim 31, wherein the plural-component fibers formed in said extruding step further include a plurality of radial segments comprising the first material and extending radially outward from said plurality of radial segments comprising the second material.

33. The method according to claim 22, wherein differential heat shrinkage of the segments at a point along the plural-component fibers and resultant fiber separation is substantially completed from application of less than approximately one second of heat.

34. The method according to claim 22, wherein said extruding step includes extruding plural-component fibers comprising: polypropylene; and polyethylene terepthalate modified with isopthalic acid and a powdered transesterification inhibitor.

35. The method according to claim 22, further comprising the step of attenuating the extruded array of plural-component fibers prior to depositing the array of plural-component fibers onto the moving surface.

36. The method according to claim 35, wherein said attenuating step includes drawing the array of plural-component fibers through an aspirator.

37. The method according to claim 36, wherein the aspirator applies hot air and/or steam to the array of plural-component fibers to cause differential heat shrinkage of the segments of the plural-component fibers prior to reaching the moving surface.

38. The method according to claim 35, wherein said attenuating step includes using at least one godet to draw or relax the array of plural-component fibers.

39. The method according to claim 38, wherein said at least one godet applies heat to the array of plural-component fibers to cause differential heat shrinkage and separation.

40. The method according to claim 22, wherein application of heat to the plural-component fibers causes the plural-component fibers to crimp.

41. The method according to claim 22, wherein said processing step comprises through-air bonding of the web by heating the web to a temperature at which segments formed of one of said first and second materials begin to melt and adhere to adjacent segments.

42. An apparatus for forming a nonwoven fabric from a process employing fiber splitting in line with fiber extrusion, comprising:

a spinpack having a spinneret with an array of orifices configured to extrude an array of plural-component fibers each comprising first and second materials having a relative difference in heat shrinkage;

a web-forming surface moving relative to said spinneret and adapted to receive the array of plural-component fibers extruded from the orifices to form a fiber web on said web-forming surface;

a heating unit configured to apply heat to the fiber web to cause differential heat shrinkage of the first and second materials, such that segments of the plural-component fibers comprising th first material separate from segments of the plural-component fib rs comprising the second material; and

means for processing the web to form the nonwoven fabric.

43. The apparatus according to claim 42, wherein said spinneret extrudes plural component fibers comprising the first and second materials having a difference in heat shrinkage of at least approximately ten percent.

44. The apparatus according to claim 42, wherein said means for processing comprises means for bonding the web to form a spunbonded fabric.

45. The apparatus according to claim 44, wherein said means for bonding performs through-air bonding of the web by heating the web to a temperature at which segments formed of one of said first and second materials begin to melt and adhere to adjacent segments.

46. The apparatus according to claim 42, wherein said spinneret extrudes plural-component fibers comprising the first and second materials which are non-hydrophilic materials.

47. The apparatus according to claim 42, wherein said spinneret is configured to extrude ribbon-shaped plural-component fibers from the orifices.

48. -The apparatus according to claim 47, wherein the ribbon-shaped plural-component fibers extruded from said spinneret comprise segments of the first material interleaved with segments of the second material.

49. The apparatus according to claim 48, wherein the ribbon-shaped plural-component fibers extruded from said spinneret are bicomponent fibers comprising alternating segments of the first material and segments of the second material.

50. The apparatus according to claim 42, wherein said spinneret is configured to extrude plural-component fibers having a cross section in the shape of a cross,

including a central segment comprising the first material and a plurality of radial segments comprising the second material and extending radially outward from the central segment.

51. The apparatus according to claim 50, wherein the plural-component fibers extruded from said spinneret further include a plurality of radial segments comprising the first material and extending radially outward from said plurality of radial segments comprising the second material.

52. The apparatus according to claim 42, wherein said web-forming surface moves relative to said heating unit such that the fiber web moves past said heating unit at a rate that allows the segments of the plural-component fibers of a portion of the fiber web to separate while the portion of the fiber web is receiving heat from said heating unit.

53. The apparatus according to claim 52, wherein said heating unit radiates heat on the portion of the web for less than approximately one second.

54. The apparatus according to claim 42, wherein said heating unit substantially completes differential heat shrinkage of the segments of the plural-component fibers of a portion of the web and resultant fiber separation, by applying heat to the portion of the web for approximately one second or less.

55. The apparatus according to claim 42, wherein said heating unit blows hot air and/or steam through the web.

56. The apparatus according to claim 42, wherein said heating unit applies radiant heat to said web.

57. The apparatus according to claim 42, wherein said spinneret extrudes plural-component fibers comprising polypropylene and polyethylene terepthalate modified with isopthalic acid and a powdered transesterification inhibitor.

58. The apparatus according to claim 42, further comprising an aspirator disposed between said spinneret and said web-forming surface, said aspirator attenuating the array of plural-component fibers extruded from said spinneret prior to the array of plural-component fibers being deposited onto the web-forming surface.

59. The apparatus according to claim 42, further comprising at least one godet to draw or relax the array of plural-component fibers.

60. An apparatus for forming a nonwoven fabric from a process employing fiber splitting in line with fiber extrusion, comprising:

a spinpack having a spinneret with an array of orifices configured to extrude an array of plural-component fibers each comprising first and second materials having a relative difference in heat shrinkage;

a web-forming surface moving relative to said spinneret and adapted to receive the array of plural-component fibers extruded from the orifices to form a fiber web on said web-forming surface;

a heating unit configured to apply heat to the array of plural-component fibers prior to deposition on said web-forming surface to cause differential heat shrinkage of the first and second materials, such that segments of the plural-component fibers comprising the first material separate from segments of the plural-component fibers comprising the second material; and

means for processing the web to form the nonwoven fabric.

61. The apparatus according to claim 60, wherein said spinneret extrudes plural component fibers comprising the first and second materials having a difference in heat shrinkage of at least approximately ten percent.

62. The apparatus according to claim 60, wherein said means for processing comprises means for bonding the web to form a spunbonded fabric.

63. The apparatus according to claim 62, wherein said means for bonding performs through-air bonding of the web by heating the web to a temperature at which segments formed of one of said first and second materials begin to melt and adhere to adjacent segments.

64. The apparatus according to claim 60, wherein said spinneret extrudes plural-component fibers comprising the first and second materials which are non-hydrophilic materials.

65. The apparatus according to claim 60, wherein said spinneret is configured to extrude ribbon-shaped plural-component fibers from the orifices.

66. The apparatus according to claim 65, wherein the ribbon-shaped plural-component fibers extruded from said spinneret comprise segments of the first material interleaved with segments of the second material.

67. The apparatus according to claim 66, wherein the ribbon-shaped plural-component fibers extruded from said spinneret are bicomponent fibers comprising alternating segments of the first material and segments of the second material.

68. The apparatus according to claim 60, wherein said spinneret is configured to extrude plural-component fibers having a cross section in the shape of a cross, including a central segment comprising the first material and a plurality of radial segments comprising the second material and extending radially outward from the central segment.

69. The apparatus according to claim 68, wherein the plural-component fibers extruded from said spinneret further include a plurality of radial segments comprising

the first material and extending radially outward from said plurality of radial segments comprising the second material.

70. The apparatus according to claim 60, wherein said heating unit substantially completes differential heat shrinkage of the segments of the plural-component fibers at a point along the plural-component fibers and resultant fiber separation, by applying heat at the point along the plural-component fibers for approximately one second or less.

71. The apparatus according to claim 60, wherein said heating unit blows hot air and/or steam through the array of plural-component fibers.

72. The apparatus according to claim 60, wherein said heating unit applies radiant heat to the array of plural-component fibers.

73. The apparatus according to claim 60, wherein said spinneret extrudes plural-component fibers comprising polypropylene and polyethylene terepthalate modified with isopthalic acid and a powdered transesterification inhibitor.

74. The apparatus according to claim 60, further comprising an aspirator disposed between said spinneret and said web-forming surface, said aspirator attenuating the array of plural-component fibers extruded from said spinneret prior to the array of plural-component fibers being deposited onto the web-forming surface.

75. The apparatus according to claim 74, wherein said aspirator serves as said heating unit and applies hot air and/or steam to the array of plural-component fibers to cause differential heat shrinkage of the segments of the plural-component fibers prior to reaching the web-forming surface.

76. The apparatus according to claim 60, further comprising at least one godet to draw or relax the array of plural-component fibers.

77. The apparatus according to claim 76, wherein said at least one godet serves as said heating unit and applies heat to the array of plural-component fibers to cause differential heat shrinkage of the segments of the plural-component fibers prior to reaching the web-forming surface.

78. A nonwoven fabric produced from a process employing fiber splitting in line with fiber extrusion, comprising:

first fiber segments comprising a first material extruded as a component of plural-component fibers; and

second fiber segments comprising a second material extruded as a component of the plural-component fibers while having a heat shrinkage different from a heat shrinkage of the first material;

wherein said first and second fiber segments have been at least partially separated from the second fiber segments by differential shrinkage induced by heat.

79. The nonwoven fabric according to claim 78, wherein said fabric is bonded to form a spunbonded fabric.

80. The nonwoven fabric according to claim 79, wherein said fabric is through-air bonded by at least partially melting one of said first and second fiber segments.

81.- The nonwoven fabric according to claim 78, wherein said second material has a heat shrinkage different from a heat shrinkage of the first material by at least approximately ten percent.

82. The nonwoven fabric according to claim 78, wherein said first and second material are non-hydrophilic.

83. The nonwoven fabric according to claim 78, wherein said first material comprises polypropylene and the second material comprises polyethylene terepthalate modified with isopthalic acid and a powdered transesterification inhibitor.

84. The nonwoven fabric according to claim 78, wherein at least one of said first and second materials includes a fluoropolymer compound and/or silicone.

85. The nonwoven fabric according to claim 78, wherein one of said first and second materials includes a foaming agent to induce swelling.

86. The nonwoven fabric according to claim 78, wherein said first and second fiber segments are segments of ribbon-shaped fibers.

87. The nonwoven fabric according to claim 86, wherein the ribbon-shaped fibers are bicomponent fibers comprising alternating first fiber segments and second fiber segments.

88. The nonwoven fabric according to claim 78, wherein said first and second fiber segments are segments of plural-component fibers having a cross section in the shape of a cross, including a central segment comprising a first fiber segment and a plurality of radial segments comprising second fiber segments extending radially outward from the central segment.

89. The nonwoven fabric according to claim 88, wherein the plural-component fibers further include a plurality of radial segments comprising first fiber segments extending radially outward from said plurality of radial segments comprising second fiber segments.

90. A product comprising the nonwoven fabric according to claim 78 selected from the group consisting of: disposable absorbent articles; medical barrier fabrics; filtration media; and sheets of padding.

91. A plural-component fiber extruded from an orifice of a spinneret, comprising: first segments comprising a first material component; and

second segments comprising a second material component having a heat shrinkage different from a heat shrinkage of the first material component;

wherein said first segments are separable from said second segments by application of radiant heat which causes differential heat shrinkage of the first and second component materials.

92. The plural-component fiber according to claim 91, wherein said second material has a heat shrinkage different from a heat shrinkage of the first material by at least approximately ten percent.

93. The plural-component fiber according to claim 91, wherein said first and second material are non-hydrophilic.

94. The plural-component fiber according to claim 91, wherein said plural-component fiber is a ribbon-shaped fiber.

95. The plural-component fiber according to claim 94, wherein the ribbon-shaped fiber comprise alternating first and second segments.

96. The plural-component fiber according to claim 91, wherein said plural-component fiber has a cross section in the shape of a cross, including a central segment comprising a first segment and a plurality of radial segments comprising second segments and extending radially outward from the central segment.

97. The plural-component fiber according to claim 96, wherein said plural-component fiber further includes a plurality of radial segments comprising first segments and extending radially outward from said plurality of radial segments comprising second segments.

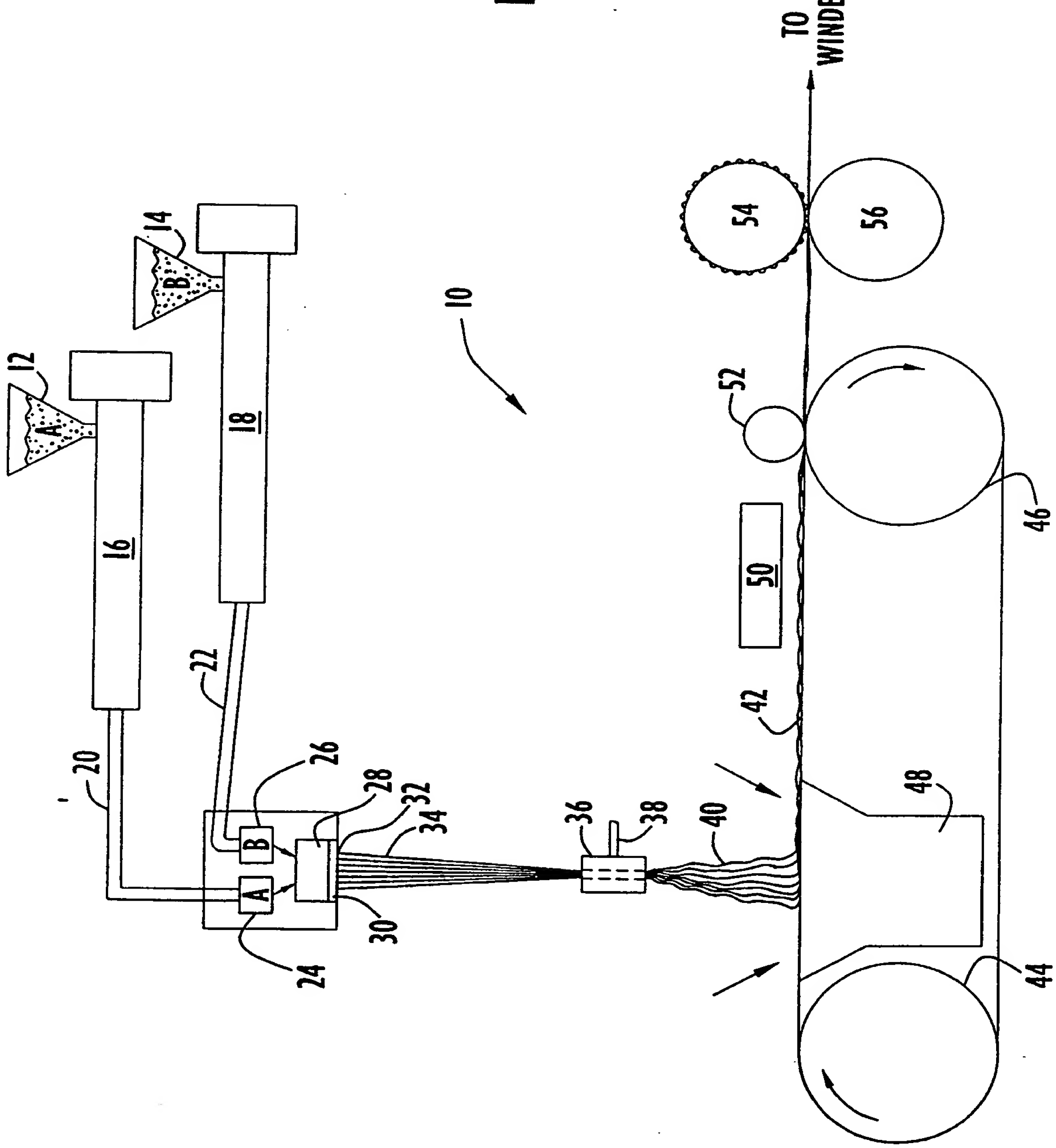
98. The plural-component fiber according to claim 91, wherein said first material component comprises polypropylene and the second material component comprises

polyethylene terepthalate modified with isopthalic acid and a powdered transesterification inhibitor.

99. The plural-component fiber according to claim 91, wherein at least one of said first and second material components includes a fluoropolymer compound and/or silicone.

100. The plural-component fiber according to claim 91, wherein one of said first and second material components includes a foaming agent to induce swelling.

FIG.1


TO WINDER
A
B
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
56

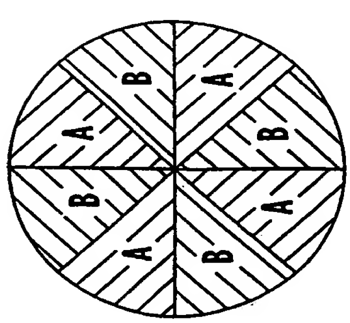


FIG.2
PRIOR ART

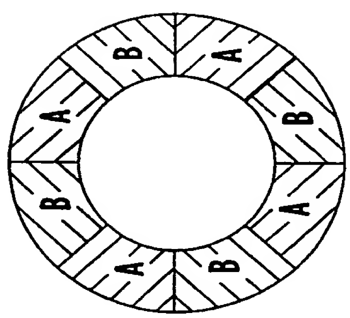


FIG.3
PRIOR ART

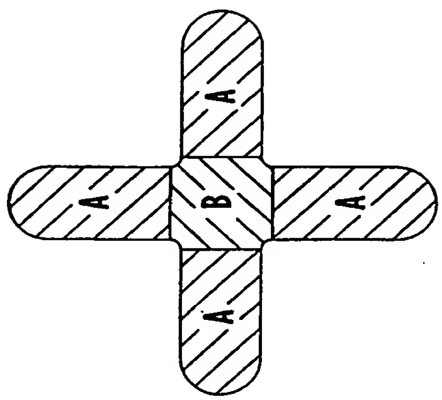


FIG.4

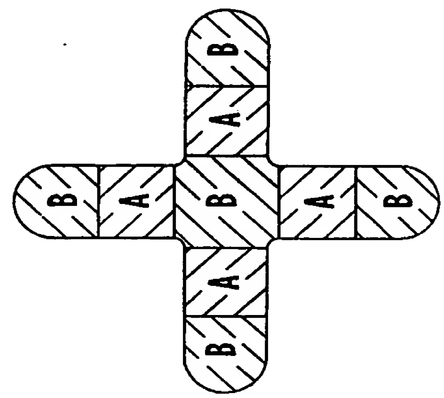


FIG.5

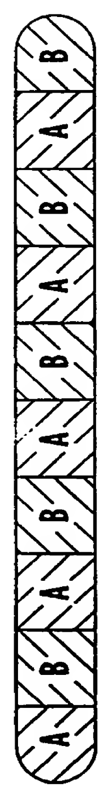


FIG.6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/21378

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B29C 47/14; D02G 3/00
US CL :156/167; 264, 147, 343; 425/66; 428/360, 374
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 156/167; 264, 147, 343; 425/66; 428/360, 374

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,108,276 A (HARTMANN) 28 April 1992, see entire document.	42-77
X -- Y	US 4,239,720 (GERLACH et al.) 16 December 1980, see entire document.	78-82, 88-90 ------------ 1-41
X -- Y	US 4,369,156 A (MATHES et al.) 18 June 1983, see entire document.	1-6,10-14, 16-27, 31-33, 35-40, 78-82, 89-93, 96-97 ------------ 7-9, 15, 28-30

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

09 FEBRUARY 1999

Date of mailing of the international search report

09 MAR 1999

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Facsimile N . (703) 305-3230

Authorized officer
TERREL MORRIS

Teleph n No. (703) 308-0661

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/21378

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A,P	US 5,718,972 A (MURASE et al.) 17 February 1998, see entire document.	1-100

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/21378

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment f additional search fees.

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING
This ISA found multiple inventions as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I, claims, 1-41 and 78-100 drawn to fibers, nonwovens and methods of making.
Group II, claims 42-77, drawn to machines.

The inventions listed as Groups I & II do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: The concept of designing machinery is a technical feature that is not found in the processes of making fibers or the fibers themselves.